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A wheat phenotyping network to incorporate physiological traits for climate change in South Asia

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ABSTRACT

South Asia, which is already home to more than one-fifth of the world's population and rapidly growing, will require wheat yields to rise annually by 2.0–2.5% to meet demand and maintain food security. To address these challenges, a wheat phenotyping network was established in the region in 2009 to support national breeding programs by applying practical phenotyping techniques to increase selection success using a cooperative multi-location testing network. A number of trials have been grown to introduce new genetic diversity for stress adaptive traits, to establish their genetic bases, and to test a new generation of lines developed using physiological approaches. The 17th Semi-Arid Wheat Yield Trial (SAWYT), consisting of a group of 50 elite spring bread wheat advanced lines, bred in Mexico using both conventional (CON) and physiological trait (PT) approaches, was grown for two seasons 2009/10 and 2010/11. Data showed that PT lines gave superior yields overall, associated with higher grain weight, and with cooler vegetative and grain-filling canopy temperatures (CT); the CT trait is considered indicative of increased gas exchange, a likely consequence in these environments of superior vascular capacity including deeper rooting to access subsoil water. Local check genotypes, which were generally well adapted to the stressed environments tended to be 3–5 days earlier to heading than CIMMYT cultivars. Results demonstrate the potential to integrate physiological breeding approaches into genetic improvement for the region, particularly as future wheat production will take place under increasing water scarcity.

1. Introduction

Wheat is the second major staple crop, after rice, in India and Pakistan and is equally important in Nepal and Bangladesh. Wheat production in South Asia (SA; comprising in this paper: Bangladesh, India, Nepal and Pakistan) has increased sixfold since the introduction of CIMMYT semi-dwarf wheat during the 'Green Revolution' of the 1960s, with present annual production of almost 115 million tonnes from a growing area of c. 39 million ha (FAO, 2012; see Table 1). These significant historical increases in productivity, driven principally by the adoption of high yielding, water and fertiliser responsive and disease resistant modern semi-dwarf

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Table 1
Population and wheat production figures for South Asia (*comprising Bangladesh, India, Nepal and Pakistan).

	Population (millions)	Population (millions; estimated)	Mean annual population growth rate (%; calculated)	Area harvested (Mha; actual)[a]	Yield (t ha^{-1}; calculated)[a]	Production (Mt; actual)[a]
Year	2010	2050	2010–2050	2010–2012	2010–2012	2010–2012
Bangladesh	149	200	0.669	0.37	2.59	0.96
India	1220	1736	0.808	29.14	3.00	86.52
Nepal	30	47	1.099	0.76	2.27	1.72
Pakistan	174	279	1.149	8.90	2.70	24.00
South Asia*	1577	2263	0.844	39.17	2.91	114.19
World	6900	9710	0.749	217.60	3.09	673.30

Source: UN (2012) and FAO (2012).
[a] Three year mean data for 2010–2012.

cultivars, the widespread use of irrigation, and expansion of the cultivated area, have helped this region to grow into one of the most populous in the world. At present it is home to more than a fifth of the world population and is anticipated to continue to grow at a rate of c. 1.8% per year to exceed 2.25 bn people by 2050 (UN, 2012). The challenge to maintain regional food security in one of the poorest regions on earth, requires an annual rise in wheat production of 2.0–2.5% through the present century to meet the estimated growth in regional demand (FAO, 2006; Rosengrant et al., 2007).

Several factors, however, are already putting pressure on wheat productivity in SA, and make the required annual growth in production look challenging, if not optimistic. Socio-economic and policy factors driving massive urbanisation – predicted to be c. 50% in 2050 (UN, 2012) – and increasing affluence will push crop production into more marginal areas, thus reducing agricultural labour and investment and increasing competition for irrigation water. Further, anthropic air pollution from these urban areas – already described as an 'Asian Brown Cloud' phenomenon (UNEP and C4, 2002) – is expected to lower the penetration of sunlight and reduce photosynthesis across much of the region. Perhaps more significantly, crops are increasingly exposed to unfavourable climatic conditions: in the short-term due to the widespread adoption of longer duration rice varieties in the predominant rice–wheat cropping system which delays the sowing of wheat and exposes the crop to high temperatures during flowering and grain-filling (Joshi et al., 2007a); and in the medium to long-term changing regional climatic patterns are likely to increase the adverse effects of heat and drought on wheat productivity (Gourdji et al., 2012).

A slowing of genetic gains for yield in wheat has already been reported (Sharma et al., 2007), particularly in low-yielding environments characterised by heat and drought stress, limited irrigation, and variable fertiliser use as is prevalent in SA (Manès et al., 2012). The annual growth of cereal production in SA during 1995–2005 was reported to be two to three times lower than during 1966–1994, and growth in yield in the early 21st century is reported to be either stagnant or slightly decreasing across the region (FAO, 2006), prompting widely reported surges in wheat prices in recent years. However, increasing climate variability will impact the continuity of wheat supply and while India has exported wheat in some years (e.g. approx. 9 Mt in 2013) it has imported wheat in other years to stabilise market demand (e.g. approx. 3 Mt in 2006; Reuters 10 May 2006). Indications are that food supply for this expanding population may fall well short of consumption if adequate measures are not taken. There is urgency to develop new input-responsive wheat varieties with higher yield potential and better water and light-use-efficiency that are buffered, genetically, against increasing heat and drought stresses – resulting from climatic change – and receding water tables. It is important that these new genotypes be input responsive and productive across a wide range of environments.

The Cereal Systems Initiative for South Asia (CSISA) was established in 2009 to support regional and national attempts to improve cereal production in SA's most important grain growing regions. A core objective of this initiative is wheat breeding (Mondal et al., 2013), and in particular, applying practical phenotyping techniques to increase selection success; commonly termed 'physiological breeding' (Reynolds et al., 2012). Using the cooperative multi-location testing and evaluation network of the International Wheat and Maize Improvement Centre (CIMMYT) established across the region, a large number of new wheat lines for breeding programs were distributed for extensive field-based testing in five international panels and prioritised for physiological trait measurement with protocols established for their assessment. Relatively easy to use and inexpensive precision phenotyping techniques were developed for large-scale assessment of materials throughout the network of testing sites. These traits include: (i) canopy temperature (CT) – with cooler canopies associated with cultivar fitness including higher photosynthetic rate (Fischer et al., 1998) and the ability to extract water deeper in the soil profile under moisture stress (Lopes and Reynolds, 2010; Pask and Reynolds, 2013a) and (ii) leaf chlorophyll concentration – higher values are generally associated with delayed senescence (Kumari et al., 2013) and improved yield under terminal heat stress (Lopes and Reynolds, 2012), In addition, phenology was scored as days to heading (DH) (Mondal et al., 2013) as this trait helps explain adaptation, physiological responses and grain yield and yield component data.

This paper will firstly describe the established CSISA wheat phenotyping network including: (i) the objectives; (ii) the sites and environments; (iii) the five international panels prioritised for physiological characterisation since 2009; and (iv) the precision phenotyping techniques employed to identify high yielding and stable lines and sources of germplasm expressing desirable traits that can be used by breeders in strategic trait-based crossing and for the development of training populations. The paper will then examine in detail the '17th Semi-Arid Wheat Yield Trial' (17SAWYT) distributed for sowing in the 2009/10 wheat season in locations across SA, and repeated at the same locations in the 2010/11 season. The main objectives of this trial were to: (i) test the expression of traits across a wide range of environments for yield predictability and yield correlations; (ii) associate traits with environmental variables to provide a better understanding of the interaction with heat and/or water-stresses, and (iii) test large scale rapid phenotyping techniques to confirm their predictability for yield and to assess the superiority of physiological trait combinations over conventionally bred advanced lines. It is hoped that the approaches adopted in this network will increase genetic gains in wheat yield in SA in the face of population growth, major abiotic challenges and threats related to climatic change.

2. Materials and methods

2.1. CSISA wheat phenotyping network

2.1.1. Objectives

Extensive field-based testing across SA is used to select and cultivate high yielding and stress-tolerant wheat cultivars using